

Nanotribology of Self-Mated Nanocrystalline and Amorphous Carbon Interfaces

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Abstract

High performance diamond and amorphous carbon thin films are attracting interest as candidate materials to enhance the tribological characteristics of mechanical components ranging in size from the macroscale to the nanoscale. These materials have been studied extensively at the macroscale, and the resulting tribo-mechanical properties measured have been shown to be excellent. However, at the micro- and nanoscale, little is known about the tribological properties and how they are affected by the chemical environment. By studying specific forms of self-mated diamond and amorphous carbon materials at the nanoscale, we have gained fundamental insights into how differences in bonding structure, film microstructure, surface chemistry, and chemical environment produce different nanotribological behavior. We have investigated three carbon-based thin film materials: ultrananocrystalline diamond (UNCD)¹, diamond-like-carbon (DLC)^{2,3}, and tetrahedral amorphous carbon (ta-C)⁴. To investigate the surface properties, we have conducted extensive surface characterizations studies using surface spectroscopy and surface microscopy techniques. To understand the surface chemistry of these materials, we utilize near edge x-ray absorption fine structure (NEXAFS) spectroscopy to determine the chemical composition and the nature of the bonds at the surface. To understand the corresponding nanotribological properties, we utilize the atomic force microscope (AFM) to measure the work of adhesion and the frictional forces for self-mated interfaces of the materials of interest. This involves a significant and novel effort to create custom-made AFM tips coated or fabricated from the carbon-based materials under study.

Consequently, we find that the nanotribological properties depend sensitively on the surface chemistry and bonding. In the case of UNCD, we can reach the van der Waals' limit of adhesion by terminating the surface with hydrogen, and we find that adhesion and friction are lower than for silicon self-mated interfaces. For DLC, we find that as relative humidity increases, friction increases monotonically, but the work of adhesion remains constant. We also find that dopants (specifically, fluorine and silicon) affect nanoscale friction and adhesion of DLC. The results from the ta-C studies demonstrate how bonding structure and nanotribological properties of the film can be correlated. We will discuss how our results can be used to tailor the surfaces of these carbon-based materials to optimize their tribological response.

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